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EXPERIMENTAL METHOD FOR BIAXIAL TENSILE STRENGTH OF FABRICS AND PRELIMINARY INVESTIGATIONS

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Summary. This paper presents a novel experimental approach to determine the biaxial strength of fabrics. A double-layer cruciform specimen was proposed based on the improvement of previous test specimen. The design and manufacture process of the novel specimen was described in detail. Uniaxial and biaxial tests of a specific material were performed subsequently. Based on numerical simulation, the biaxial strength of the fabrics was preliminary investigated. And the correlation between uniaxial and biaxial strength of the material was discussed. The proposed experiments could characterize the biaxial strength of fabrics, and the biaxial strength of the fabrics at 1:1 tension is higher than the weft strength and little lower than the warp strength.

1 INTRODUCTION

With its unique material features such as light weight, high strength, economical costing and extraordinary aesthetic expression [1,2], fabrics provides a widely applicative construction material. For more than 40 years, fabrics were employed in the fields of architecture and aerospace engineering. To analyse the structural load response and enhance the service reliability, the mechanical behaviour of fabric materials was desired.

According to previous research, the mechanical properties of fabrics differs significantly from the traditional construction materials [3,4]. Results from the special manufacture process, the mechanical performance of fabric materials showed prominent orthotropy [5]. Usually, the spinning process of fabrics was weft yarns going up and down through the straight warp yarns. Therefore, the warp direction of fabrics normally possesses a higher stiffness level and uniaxial strength. For the purpose of revealing the mechanical performance of fabrics, uniaxial and biaxial tensile tests have been widely used. Kang el al. [6] focused on the mechanical property characterization of film-fabric laminate for stratospheric airship envelope. They performed uniaxial tensile tests in thermal chamber at low, room and high temperatures to investigate the tensile property and temperature dependency. Blum and Balz [7] developed a biaxial tension instrument for fabrics, and a linear stress-strain increment model was proposed for specific materials. Chen and Chen [3] performed the tearing analysis on laminate fabrics used in pneumatic structures. Uniaxial and biaxial tearing tests were conducted thoroughly. It was found that the tearing strength and failure performance were significantly related to the biaxial stress ratios.

Since the working condition of fabrics is generally under biaxial compound load. Biaxial parameters could give a better mechanical explanation of the material, which is close to the practical service state. However, previous research only focused on elastic constants determination and uniaxial strength measurement. The biaxial strength, one of the key parameters of fabrics, remained unsolved. Based on Japanese standard [9] and European design guidance [10], the current biaxial specimen of fabrics can only be applied in elastic constants tests, where the load level was usually limited under 30% of the uniaxial tensile strength. With a higher load vale, the failure of specimen would occur at the arm of the cruciform, tear propagate at the end of slits or the corner of the arm due to stress concentration. Such failure performance cannot characterize the real biaxial strength of fabrics, and a new experimental approach is therefore needed.

This paper proposed a new cruciform specimen aiming to solve this problem. In order to obtain the authentic biaxial failure, the strength arrangement of the traditional cruciform specimen was optimized and a double-layer cruciform specimen was designed. Strength tests were fulfilled for specific laminate fabrics under both uniaxial and biaxial conditions. And preliminary analysis was performed utilizing numerical simulation.

2 METHODOLOGY

2.1 Material

To reach both mechanical requirements and the workability demands, fabrics are usually manufactured through multi layers laminated on a base cloth. The base cloth comprises warp and weft yarns interweaving, and the external load is mainly born by it. At the same time, various kinds of materials can be employed as the functional layers, which are utilized to enhance the workability. The typical composition of fabrics is illustrated in Figure 1.

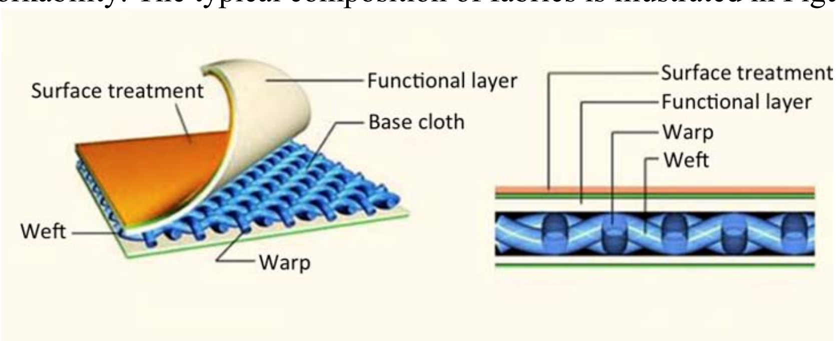

Figure 1: Typical composition of fabrics

In this study, a specific fabric was selected as the sampling material, and the basic specification of the material are listed in Table 1. In accordance with the precious description, the fabrics possessed a high strength with light weight.

Table 1: Basic specification of the sampling material

Variable	Specification
Thickness	0.20mm
Areal density	250g/mm^2
Weave Count	48*48 ends/5cm

2.2 Uniaxial specimen and tester

In line with the ISO testing standard, a stripe-shape specimen was employed in the uniaxial tensile test. The width of the specimen was 50mm and the length was 600mm. At each end of the specimen, a 200-mm-length clamping region was flattened for the clamping. On the other hand, a uniaxial tensile tester was utilized to fulfill the experimentation. Under the uniaxial tester, replaceable clamping provided stable load application. And a monitor system would record the test data for further analysis. The appearance of the uniaxial tester is demonstrated in Figure 2. Three uniaxial specimens were prepared for consistency.

Figure 2: Uniaxial tensile tester

2.3 Biaxial specimen and tester

As discussed previously, biaxial specimens suggested by current criteria only suits for elastic constant determination. The failure would occur at the loading arms when the biaxial load reaches a high level,however it cannot characterize the biaxial strength of fabrics yet. In order to obtain the authentic biaxial tensile failure, a novel double-layer specimen was proposed and manufactured. Since the stress concentration was the main reason leading to the unsatisfactory test results, a direct optimization was to rearrange the strength layout. With relatively stronger loading arms, the biaxial failure would occur at the core region of the specimen.

To achieve the ideal strength configuration, the arms of the cruciform specimen were prolonged. With each arm folding back and gluing onto the top of the first layer, a double-layer specimen was created. The plane and sectional diagram of the novel biaxial specimen is displayed in Figure 3

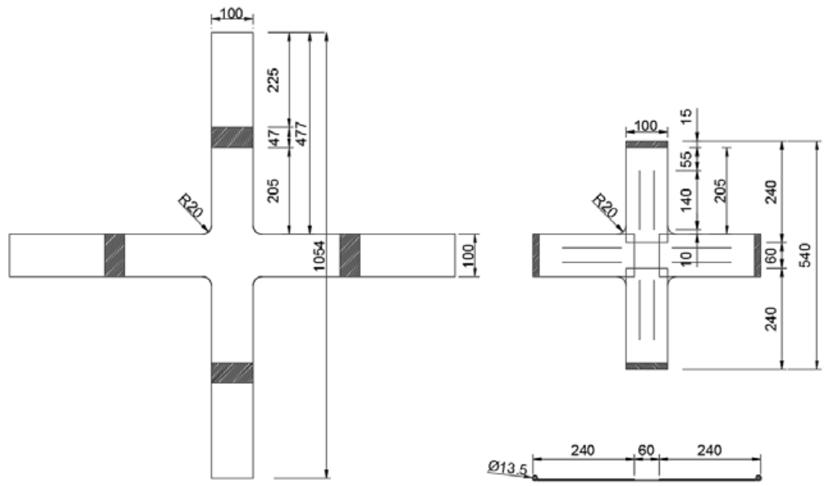

Figure 3: The novel biaxial cruciform specimen (unit: mm)

As shown in the figure 3, an ethylene propylene diene monomer(EPDM) bar was installed at each end of the cruciform arm. Three slits were cut at each loading arm every 33mm. when biaxial tensile load was applied to the specimen, these slits would ensure the stress uniformity at the core square.

Furthermore, an advanced biaxial tester was developed in our laboratory. The controllable biaxial load was applied through four high precision servo hydraulic cylinders at each end of the cruciform, the load and displacement value can be measured and recorded accurately with the computer monitor system. Two biaxial specimens were prepared for consistency.

2.4 Experiments

For both uniaxial and biaxial tensile tests, the specimens were clamped firmly onto the tester at first. A pre-load of 0.5N/mm was applied to ensure the flatness of the specimen. With the installation error less than 0.3%, the load was applied at a velocity of 0.1N/mm. The experimental process was performed at a temperature of 19±1 °C and a 41±3% humidity.

3 RESULTS AND DISCUSSION

3.1 Failure performance

At a certain loading rate, the specimen would rupture under tensile load. The typical failure performance biaxial specimen was illustrated in Figure 4.

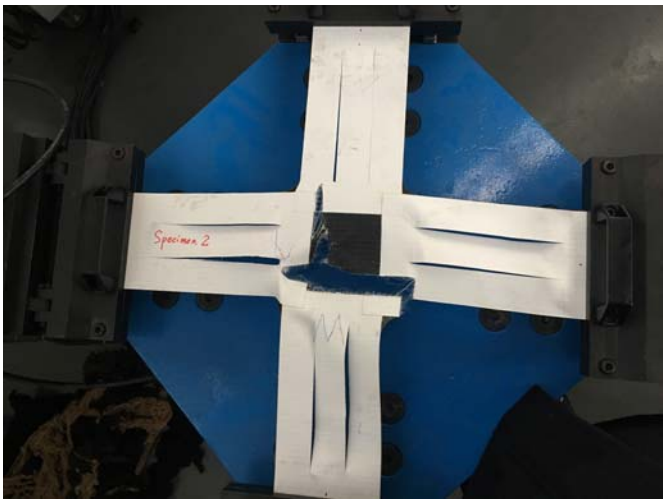

Figure 4: Typical failure appearance of novel biaxial specimen

As shown in the figure 4, a cross slits failure occurred at the center of the fabric specimen. Both warp and weft directions ruptured under a 1:1 biaxial loading condition, which may also justify the novel design. According to the straight fracture morphology and test observation, it can be concluded that the biaxial failure was brittle failure. In the future, a high-speed camera should be introduced to detect the failure process accurately.

3.2 Numerical analysis

To reveal the authentic stress value at the core square of the specimen, a preliminary numerical analysis was fulfilled utilizing finite element software ABAQUS. The geometrical information was accurately built in the model. The specimen was defined as shell element of orthotropy. The elastic constants were determined based on the linear section of uniaxial test results. Since the biaxial load was applied in perpendicular directions, the plane principal stress should be considered as the representative results instead of Mises stress. The principal stress in warp direction (S_{11}) was reported in Figure 5.

As shown in the figure, the maximal stress of the specimen appeared nearing the rim of the single-layer core square. The simulation results coincided with the experimental results properly. When the biaxial load continued to increase, the failure would occur at this position. Meanwhile, the stress uniformity of the specimen can also be justified.

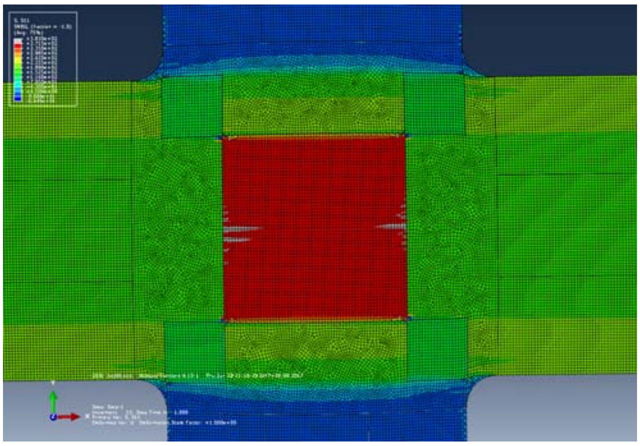

Figure 5: The principal stress in warp direction based on numerical simulation (unit: MPa)

3.3 Biaxial tensile strength determination

According to the experimental data and numerical simulation, preliminary analysis on the biaxial strength of fabrics was conducted. The specific results are listed in Table 2.

Table 2: Bixial strength of fabrics

Uniaxial strength (warp)	88.61kN/m	Uniaxial strength (weft)	69.43kN/m
Biaxial strength		85.88kN/m	
Strength ratio (biaxial to warp)	0.969	Strength ratio (biaxial to weft)	1.23

As can be observed in Table 2, the biaxial strength of the fabric was between the warp and weft uniaxial strength under a 1:1 load ratio. Other than the traditional viewpoint, the authentic biaxial strength may be higher than the lower uniaxial strength. Future research should focus on a wider material range and failure process analysis.

4 CONCLUSIONS

- A novel biaxial cruciform specimen was firstly proposed for the biaxial strength determination of fabrics. Tensile tests were performed on both uniaxial and biaxial tests. It was obtained that a cross slits failure may appear at the biaxial failure in the center single layer of the cruciform.

- The preliminary analysis of the biaxial strength was fulfilled based on the numerical simulation. It was found that the biaxial strength was higher than the weft strength and lower than the warp strength. It is different from the published conclusions that the design strength of fabrics should consider a reduction factor about 0.85 due to biaxial tensile effects with respect to uniaxial tensile strength

- Future research may carry out extensive experiments with various tensile stress ratio, different fabrics, various loading rate, and formulate biaxial strength criteria, etc.

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